TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 878

EFFECT OF FILLERS AND OF MIXING PROCEDURE ON THE STRENGTH OF PLASTIC MATERIALS

By William Kyncch and L. A. Patronsky
University of Michigan

Washington
January 1943

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 878

EFFECT OF FILLERS AND OF MIXING PROCEDURE ON THE STRENGTH OF PLASTIC MATERIALS

By William Kynoch and L. A. Patronsky

INTRODUCTION

It is well known that the strength and other important physical properties of molded parts or articles made from synthetic-resin plastics may be modified over a considerable range by varying the proportion of filler present in the molding powder. As a variety of fillers may be used and as the nature and amount of other ingredients of the powder, the method of mixing, the molding temperature, the pressure, and other factors may also be varied, a large number of combinations is possible. Knowledge of the effect of changes in these variable factors on the properties of molded products is constantly being extended. The present study deals with a small part of the extensive field of investigation indicated.

The specific object of the present study was to prepare a series of molding powders with the use of a given plastic and given fillers in varying proportions and to determine the effect of the differences in composition of these molding powders on certain physical properties of standard test pieces molded from them. As the effect of differences in the proportion of filler was the only phase to be investigated at this time, methods of mixing, grinding, etc. were standardized to approximate those methods common in industrial practice.

Part I covers the effect of fillers and part II the effect of mixing procedure.

I. EFFECT OF FILLERS

MATERIALS

The plastic used was Durite resin No. 221-x, a phenol-furfural resin extensively employed by industrial molding plants equipped to make up their own molding compounds. The fillers were wood flour made from white pine (Pinus strobus) of three different degrees of fineness: coarse, medium, and fine. The original intention was to work also with carbon black as a filler. A preliminary study, however, indicated that, with the methods adopted, flexural strength obtainable with this material was very low as compared with that attainable with wood flour. For this reason work on carbon black was discontinued. Results of the preliminary flexural tests are given in part II.

The wood flour was supplied to conform to the following requirements:

Coarse: All coarse-ground flour sifted through a No. 50 sieve and was retained on a No. 100 sieve

Medium: All medium-ground flour sifted through a No. 50 sieve and was retained on a No. 200 sieve

Fine: All fine-ground flour sifted through a No. 100 sieve and was retained on a No. 200 sieve

As these requirements do not exactly correspond to those of any wood flours ordinarily marketed, it was necessary to have the flour specially prepared. No lubricants or plasticizers were incorporated with the molding powders. It was necessary, however, to apply a film of beeswax to the molded surfaces in order to facilitate removal of the specimens from the mold cavities.

PROCEDURE

Batches

For each of the three fillers, nine batches of material, each approximately 8 pounds in weight, were prepared as indicated in the following table:

Batch	Material (by weight)	
	Filler (percent)	Resin (percent)
a	0	100
b	10	90
c	20	80
d	30	70
e	40	60
f	50	50
g	60	40
h	70	30
i	80	20

Three additional batches (one for each filler) of the 50-50 class and two additional batches representing the highest and lowest wood-flour content were also made up for preliminary experimentation.

Preparation of Materials

First drum mixing.- Uniform mixing of filler and resin was secured at this stage by running each batch, except the batch containing resin without filler for a 5-minute period, at room temperature, in a drum containing a number of hardwood blocks and rotated at approximately 75 rpm. The drum was thoroughly cleaned after each batch was run.

Banbury mixing.- Each batch was then mixed in a 2-B Banbury mixer, to the jacket of which a steam line had been connected in order to obtain the required temperatures. A jacket temperature of 248° F and a rotor temperature of 210° F were maintained during the mixing period. Great care was taken to maintain uniformity of mixing conditions throughout. After the Banbury mixer was charged with the material to be mixed, the start of the actual mixing period, which required that the resin be softened and melted to a degree that would allow of satisfactory mixing, was determined by noting the time at which a sudden increase in the motor amperage occurred. A mixing period of 60 seconds was used. On completion of mixing the steam was turned off and cooling water was run into the jacket. When the mix cooled sufficiently, it was chipped out of the Banbury mixer. The mixing conditions, as stated, were approved by the makers of the resin employed.

The Banbury mixing of the material was preceded by considerable preliminary experimental work required to insure that satisfactory mixing conditions could be obtained and that these conditions could be accurately controlled and reproduced.

Grinding.- Much of the material, as it came from the Banbury mixer, was in relatively large lumps, together with coarse particles of various sizes. Each batch was next ground in a Sturtevant Mill Co. grinder having two smooth-faced steel rolls. Much preliminary work, such as determining optimum adjustment of the grinding space and grinding periods necessary to expedite production of the required proportions of particles of the different sizes desired, was required to develop a satisfactory procedure in this part of the work.

Sieving.- After being ground, the material of each batch was passed through a motor-operated shaker sieve and particles of the different sizes were thus segregated. The required proportion, by weight, of particles of each size was then weighed out and the whole put together to constitute the batch. The sieve analysis used, specified by the manufacturers of the resin employed, was as follows:

Sieve Analysis

	Percent
through 14 mesh	100
on 20 mesh	9
on 40 mesh	42
on 60 mesh	20
on 80 mesh	8
on 100 mesh	4
through 100 mesh	17

Second drum mixing.- After being sieved, each batch of mix, was run for a 5-minute period, at room temperature, in the mixing drum used for the first drum mixing.

Molding

All molding was done in an Elmes 20-ton hot-plate press. (See fig. 1.) Calibration tests were run on this press by means of an Amsler calibrator. (See calibration curve, fig. 2.)

The dies used in molding comprised one 5-impression die (fig. 3) for production of the 1/2- by 1/2- by 5-inch test pieces specified for the A.S.T.M. standard flexural-strength test on molded plastics (A.S.T.M. designation: D 48-39) and one single-impression die (fig. 4) for production of the 1/8- by 2-inch test pieces to be used in the standard water-absorption test on plastics (A.S.T.M. designation: D 570-40T).

In connection with molding, a study of preforming procedure was conducted. Preforms were designed and constructed and the effect of various preform dimensions and pressures on the blanks and on the final test pieces was investigated. Preform methods were found to be of particular importance in relation to the flexural test pieces. Each of the five test pieces made at one pressing operation in the five-impression mold should, of course, be as nearly as possible identical with the others. In order to insure this result, careful preforming procedure is necessary. The weight of molding powder used for each blank should be the same within the limits of experimental error. The dimensions of each blank should also be the same and the clearance between the blank and the die cavity into which it is inserted should be such that the blank will just pass into the cavity.

It was found that, when flexural test pieces from batches containing high percentages of wood flour were preformed, very rapid recovery (increase in size) of the blank occurred after removal from the preform. It was necessary to reduce the size of the preform in this case to dimensions providing proper allowance for this recovery. Batches with low wood-flour content differed appreciably in this recovery behavior from those with high wood-flour content. Increase in preforming pressures appeared to expedite recovery. The best preforms resulted from material of high filler content.

Careful preforming methods also proved to be of importance in obtaining uniform cure of test pieces in the molding operation. A preforming pressure of 8000 pounds per square inch was used for all specimens.

Two molding temperatures to be used throughout the work were selected, namely, 325° and 375° F. These temperatures were decided upon after discussion with the manufacturers of the resin used and after trial work on molding at various temperatures. In actual practice, variation in mold temperature during the molding period of 15 minutes was unavoidable. An effort was made to maintain an average of either 325° F or 375° F over the molding period. Typical temperature variations are shown in tables 1 and 2.

Two molding pressures to be used throughout the work were selected, namely, 2000 pounds per square inch and 3000 pounds per square inch. These pressures were chosen following consultation with the manufacturers of the resin and trial molding at various pressures. These pressures were very closely adhered to in molding all test pieces for use in the standard tests used.

A molding period of 15 minutes was decided upon after consultation and trial work. In trial tests on the water-absorption disks and flexural test bars, blistering frequently occurred. This condition arose from failure of the gases generated in the molding operation to escape from the die. This difficulty was overcome by rapidly raising the molding pressure to about one-fourth the total load in pounds per square inch (at specified molding temperature), maintaining it at that point for 15 seconds, releasing and opening the press slightly to allow gases to escape, then rapidly closing the press and increasing the load to full molding pressure.

In the course of preliminary molding on the flexural-strength test bars, it was noted that the cure of the plastic was not complete in the center portion of the test bar when the bar was molded to a full $\frac{1}{2}$-inch thickness. In order to overcome the improper cure and to develop the maximum strength of the plastic material, the thickness of the flexural-strength test bars was reduced to approximately 5/16 inch.

Testing

The tests carried out were flexural strength (A.S.T.M. designation: D 48-39), water absorption (A.S.T.M. designation: D 570-40T), and specific gravity (A.S.T.M. designation: D 71-27). All tests were conducted in strict conformity with the directions set forth in these standards.

A Riehlé universal testing machine was used in making the flexural tests; the necessary accessory equipment (see fig. 5) was designed and constructed. Dynamometer calibration tests were run on the Riehlé machine. (See table 3.)

The specifications for the flexural test call for a testing machine head speed not to exceed 0.050 inch per minute when the machine is running idle. As a check on the computed speed obtained with appropriate gear combinations and motor speed, head-speed tests were run on the Riehlé machine. (See table 4.)

The water-absorption test required immersion of the test disks in water maintained as nearly as possible at a constant temperature of 77° F ± 3.6° F. An apparatus giving the desired temperature control was designed and constructed and gave very satisfactory results when tested. The apparatus consisted of a cylindrical sheet-metal container about 22 by 30 inches, including the lid. Inside this container was placed a similar but smaller container, about 12 by 18 inches, fitted with a thick wooden lid. The space between the inner and outer containers was filled with dry wood shavings. The water in the inner container was heated by means of a small electric unit controlled by a thermostat.

The specific-gravity determinations were made by the water-displacement method. Before this method was adopted, check determinations were run to ascertain the magnitude of the error that might occur because of absorption of water by the specimen during the specific-gravity test. The results of these check determinations, presented in table 5, indicated that the error was of negligible proportions.

RESULTS

Considerable difficulty was experienced in molding the material containing 80-percent filler because the amount of resin was insufficient properly to bind the filler. Frequently, when the specimens were removed from the mold after curing, they separated longitudinally along the center. It was extremely difficult to obtain a specimen of tho 80-percent filler material that showed a uniform coloring because of its poor flow quality.

The material containing 70-percent filler and 30-percent resin showed a marked improvement over the 80-percent filler material in molding characteristics. Although the flow was quite poor, good test specimens were obtained with no longitudinal separation. The color of specimens was uniformly dark brown.

The molding characteristics of the materials containing 60-, 50-, 40-, and 30-percent filler were very good. A good flash formed, the color was uniformly dark brown, and the surface finish was very good with all conditions of temperature and pressure used.

The materials containing 20-percent filler and 10-percent filler again became difficult to mold because of high flow properties and the consequent loss of plastic in the form of flash. It was necessary to close the mold very slowly to prevent excessive squeeze out.

The zero-percent filler material (straight resin) presented difficulties in molding due to excessive blistering and longitudinal separation, as in the case of the 80-percent filler material.

Good specimens from both the 80-percent and zero-percent filler batches were difficult to obtain, which accounts for the wide range in flexural strength for the material.

Table 6* contains the results for the tests of flexural strength and specific gravity determinations.

Table 7* contains the results of water-absorption tests.

Discussion of Results

Variation in results.- The utmost care was exercised in the entire procedure from the preparation of the molding materials to the final compilation of the results. In spite of every precaution taken to avoid sources of error in using uniform methods of mixing, grinding, molding,

*Available for reference or loan in the Office of Aeronautical Intelligence, NACA.

and testing, an inexplicable variation in results was evident. This fact has been noticed by other investigators of the strength properties of plastics (reference 1).

The range in variation could probably have been reduced by having a large number of test specimens for every material and condition of molding. Owing to the wide range of materials and molding conditions investigated, it was beyond the scope of this work to test more than three specimens for water absorption and more than five specimens for determination of flexural strength. Although the results should not be considered as representing exact flexural-strength and water-absorption properties, they can be accepted as sound indications of those properties.

Tests of water absorption.- The indication most evident from the tests of water-absorption properties is that the grade of wood flour - fine, medium, or coarse - has no effect on the water absorption of any resin-filler combination tested.

There is no indication that the molding pressure of 3000 pounds per square inch imparts a greater resistance to the absorption of water to any given material than does the molding pressure of 2000 pounds per square inch.

Table 8 and figure 6 clearly show that the absorption of water by the phenol-furfural plastic investigated is affected by the temperature of molding. A molding temperature of 325° F gave a more water-resistant plastic than did a molding temperature of 375° F.

The only visible change in the water-absorption specimens that took place during the 24-hour immersion period was a slight loss of surface luster.

Specific gravity.- The results as shown in table 6*, column 13, and in figure 7 show conclusively that the specific gravity of any given phenol-furfural resin-wood flour filler material is a function of the proportion of wood flour to resin.

Additions of 10-percent increments of filler content increased the specific gravity of the material by approximately 0.013. The relationship appears to be a straight-line one; the greater the percentage of wood-flour filler, the higher the specific gravity.

---

*Available for reference or loan in the Office of Aeronautical Intelligence, NACA.

Molding temperatures and pressures used in this work did not have a great influence on the specific gravity of any given molded product.

Flexural strength.- Figure 8 compares the flexural strengths obtained with various percentages of fine, medium, and coarse wood flour as filler in a phenol-furfural plastic. In almost all of the cases the maximum fiber stress appeared to attain the highest point between 70 percent and 60 percent of wood flour. The flexural strength then decreased with decrease in percentage of filler. In the range of 40-percent to 30-percent filler the flexural strength again increased to a second peak, although not so high as the 70-percent to 60-percent strength peak. The indication that the strength of the 50-percent filler and 50-percent-resin combination is usually lower than the strength on either side of a 50-percent-filler material gives valuable data for specification in industrial applications. If high strength is required and high flow properties not needed, the 70-percent- or 60-percent-filler material could be specified. If high flow is needed and strength is of secondary importance, the 40- percent or 30-percent filler could be satisfactorily employed.

The effect of the grade of wood flour on the flexural strength is only slight. The specimens molded at 325° F and 2000 pounds per square inch (fig. 8(a)) show that coarse wood flour gives the highest strength, medium wood flour is second in strength, and fine wood flour the lowest in strength. The specimens indicated by the strength curves shown in figure 8(b) were molded at a temperature of 325° F and a pressure of 3000 pounds per square inch. Where coarse and medium grades of wood flour were used as fillers, the material that was molded at 325° F and at a pressure of 3000 pounds per square inch behaved very much the same as it did under the molding conditions of 325° F and pressure of 2000 pounds per square inch, except that the maximum fiber stress attained at 325° F and 3000 pounds per square inch was lower than the maximum fiber stress obtained under the molding conditions of 325° F and pressure of 2000 pounds per square inch.

A comparison of figures 8(a) and 8(b) indicates that the strength of the material containing fine wood flour as filler increased decidedly under the more severe molding conditions, especially in the 40-percent material.

Figures 8(c) and 8(d) present the flexural-strength curves for the molding conditions at 375° F with 2000- and 3000-pounds-per-square-inch pressure, respectively. From these curves it may be noted that the coarse wood-flour-filled material does not give the highest strength as was the case when the material was molded at the lower curing temperature. The highest maximum fiber stress was attained with the fine wood-flour-filled material containing 40-percent filler. The flexural strength of material with the coarse wood-flour filler is clearly seen to drop, probably as a result of the high molding temperature of 375° F (figs. 8(c) and 8(d)).

With the plastic of 60-percent coarse wood-flour filler, the highest maximum fiber stress was obtained at the molding temperature of 325° F and the pressure of 2000 pounds per square inch. With the 40-percent fine wood-flour-filled material, the highest maximum fiber stress was obtained at the molding temperature of 375° F and pressure of 3000 pounds per square inch. These results indicate that, in order to develop the highest strength for any grade of wood flour as a plastic filler, careful study should be made to determine the proper molding temperature and pressure for that particular grade of wood flour.

Figure 9 presents the same data shown in figure 8, except that each set of curves is for one grade of wood flour molded at the various conditions of temperature and pressure.

Figure 9(a) clearly shows that the strength of the 50-percent wood-flour-filled material is decidedly lower than that of the material with 60-percent filler or 40-percent filler. These curves also show that, when the fine grade of wood flour is used, the highest maximum fiber stress is developed by using the most severe molding conditions.

Figure 9(b) shows the results for the medium grade of wood flour molded under the various molding conditions. In this case, the maximum fiber stress is developed with 60-percent medium wood flour molded at a temperature of 325° F and 3000-pounds-per-square-inch pressure. The highest strength in the cases where 40-percent or 30-percent filler was used was obtained at the molding condition of 375° F and 3000 pounds per square inch.

The maximum strength, when coarse wood flour was used as the filler, was developed by applying the milder conditions of temperature and pressure (325° F and 2000 lb/sq in. pressure). (See fig. 9(c).)

CONCLUSIONS

The following conclusions apply to part I: These results appear to lead to the conclusion that when a coarse wood-flour filler is used in about the proportion of 60-percent or 70-percent filler, the molding temperature of 325° F and pressure of 2000 pounds per square inch will give high strength. When high strength is desired in a 30-percent to 40-percent wood-flour-filler material, a fine wood-flour filler should be used with a molding temperature of about 375° F and a pressure of about 3000 pounds per square inch.

Because the maximum strength in the case of the coarse wood-flour filler was obtained at the mildest molding conditions (temp., 325° F and pressure, 2000 lb/sq in.), the indications are that perhaps even higher strength could be expected from this material at lower temperatures and pressures. Also, from the results of the high strength in the case of the fine wood-flour filler at the most severe molding conditions (temp., 375° F and pressure of 3000 lb/sq in.) the indications are that higher-strength molded material could be expected from similar material with higher temperatures and pressures. Inasmuch as time did not permit investigations in a greater range of temperatures and pressures, it must be left to future work to determine the optimum conditions for producing the highest-strength molded products using coarse and fine wood flour as filler.

II. EFFECT OF MIXING PROCEDURE ON STRENGTH OF TEST BARS CONTAINING CARBON BLACK FILLER

In the course of the preliminary molding and testing of materials, it was noted that test specimens containing carbon black as a filler showed pronounced weakness and very poor molding characteristics. These characteristics were so marked that it appeared questionable that any information of value could be obtained by conducting the number of tests planned for this material as a filler.

Although research in mixing and compounding of the plastic materials was not originally planned in the project, it was felt to be highly desirable to ascertain whether the strength of the molded product could be appreciably increased by reprocessing the molding powder in various ways. The work was therefore conducted. In addition, an entirely different method of preparing the molding material was tried.

Increased strength was obtained as a result of reprocessing the carbon-black molding powder, but the strength still remained very low as compared with that of bars made from molding powder in which wood flour was used as the filler. The molding characteristics after reprocessing were unchanged.

Since powder containing 50-percent filler and 50-percent resin is considered a general-purpose molding powder, such a formulation was considered to be best suited for this work. In order to have some basis upon which to rate the strength of the test material, a commercial plastic, Durite, of the same filler-resin proportions as the carbon-black material, was molded under the same conditions as the test material.

PROCEDURE

Preparation of material.- The materials that were tested for maximum fiber stress were prepared in the following way:

1. Durite was prepared commercially by Durite Plastics Inc., Philadelphia, Pa.

2. For a standard mix of wood flour and resin, equal proportions of wood flour (medium grade) and Durite resin were mixed in a tumbling drum for 10 minutes. The material was then compounded for 60 seconds in a small Banbury mill in which the rotor was heated to 248° F and the jacket to 210° F. This process kneaded the plastic mass and thus caused the melted resin to coat the wood-flour particles. The resulting chunks of plastic were then processed by a Sturtevant mill until all the particles passed through a 14-mesh screen. The material was then ready for molding. The same procedure was followed as for wood-flour fillers described previously in this report.

3. The mix of carbon black and resin was prepared identically as the wood flour-resin material, except that, subsequent to the regular grinding process, the material was reground in a ball mill in an attempt to improve the distribution of resin and carbon black. One batch was processed in the ball mill for 24 hours. To the second batch 3-percent water was added and the batch was then processed for 48 hours in the ball mill.

4. For a mix of carbon black, resin, and acetone, 1 pound of Durite resin was dissolved in 500 cubic centimeters of acetone. One pound of carbon black (filling grade) was gradually introduced into this solution and mixed with a hand beater for 15 minutes. The material was then poured into a large shallow tray to allow the acetone to evaporate. After the complete evaporation of the acetone, the material was placed in a ball mill and ground for 30 minutes.

5. For a mix of wood flour, resin, and acetone, the same procedure was followed as for the carbon black-resin-acetone mix, except that 1000 cubic centimeters of acetone were needed to soak the wood-flour filler completely.

Molding.- Four molding conditions were selected for this study to see what effect various molding pressures and temperatures would have on the strength of the molded plastics. The molding conditions used were as follows:

Temperature (°F)	Pressure (lb/sq in.)
325	2000
325	3000
375	2000
375	3000

The molding period in all cases was 15 minutes. The molding was done in a standard A.S.T.M. designation five-impression 1/2- by 1/2- by 5-inch bar mold. Preforms were used in order to minimize errors that might arise due to unequal amounts of molding material in the five cavities. Each preform contained 20 grams of molding powder except in the case of the very finely ground carbon black-resin material, of which 22 grams were used. The preforms were put into the mold as quickly as possible and the mold closed rapidly. The full pressure was maintained in each case for a curing period of 15 minutes.

Testing procedure.- The bars were tested for flexural strength (A.S.T.M. designation: D 48-39). The method is described in part I.

RESULTS

The thickness and width of each specimen as molded were measured with a dial micrometer to the nearest one-thousandth of an inch. The load and deflection of each specimen were recorded. The rate of load application was 0.049 inch per minute. The maximum fiber stress in pounds per square inch was calculated from the formula:

$$S = \frac{3\ Pl}{2\ bd^2}$$

where

S maximum fiber stress

P load applied

l distance between points of support

b width of beam as tested

d depth of beam as tested

The results of the tests are summarized in table 9 and figure 10.

CONCLUSIONS

The following conclusions apply to the tests of part II:

1. As previously indicated in this report, the results of the flexural-strength tests clearly indicate that the molded plastic using carbon black as a filler in a phenol-furfural resin is very inferior to a wood flour-resin plastic in the function of maximum fiber stress.

2. In many specimens molded, minute cracks form on the surfaces of the bar which resembled "crazing" of a finished surface. These cracks penetrated very deeply into

the test bar, as frequently the specimen separated along one or more of the cracks during the conditioning period. The poor molding characteristics of the carbon black-resin material is further indicated by the fact that out of five bars that were molded under each condition of temperature and pressure frequently only one specimen remained intact for testing.

3. The acetone-mixed wood-flour material showed flexural strength comparable with that of the standard mix and the Durite wood-flour-filled material. The acetone-mixed carbon-black plastic compares very favorably in flexural strength with the reprocessed standard mix carbon-black plastic. There was no indication that superior strength could be obtained by compounding the molding powders by the acetone mixing method.

It is quite possible that the procedure used in the mixing of the carbon black-resin material was not the procedure best suited for the material. Since the compounding of the materials by different methods was beyond the scope of the project, it was decided that the indicated properties of the carbon-black plastic did not justify the time and expense required to carry out the molding and testing.

Department of Engineering Research,
University of Michigan,
Ann Arbor, Mich., June 1942.

REFERENCE

1. Burns, Robert W., and Werring, Walter W.: Impact Testing of Plastics for Use in Molded Phenol Plastic Telephones. Modern Plastics, vol. 15, no. 12, Aug. 1938, pp. 37-41, 52, 54, and 56.

TABLE 1

TYPICAL TEMPERATURE VARIATIONS DURING MOLDING PERIOD

[Nominal molding temp., 325° F]

Charging (min)	Mold temp. (°F)
0	328
3	326
4	326
5	325
6	324
7	324
8	324
9	324
10	325
11	326
12	327
13	328
14	328

TABLE 2

TYPICAL TEMPERATURE VARIATIONS DURING MOLDING PERIOD

[Nominal molding temp., 375° F]

Charging (min)	Mold temp. (°F)
0	379
3	370
4	372
5	375
6	376
7	378
8	379
9	380
10	380
11	378
12	376
13	375
14	374

TABLE 3

CALIBRATION OF 60,000-POUND RIEHLÉ TESTING MACHINE

FOR PLASTIC RESEARCH

[Spring-dynamometer method; capacity of dynamometer, 2000 lb]

Ames dial reading	Actual load on dynamometer (lb)	Riehlé reading: First trial (lb)	Riehlé reading: Second trial (lb)	Riehlé reading: Third trial (lb)	Riehlé reading: Average (lb)	Error of testing machine (lb)
0.0351	200	202	200	200	200.7	0.7
.0692	400	390	387	387	388.0	-12.0
.1048	600	597	597	595	596.3	-3.7
.1382	800	800	800	800	800.0	0
.1710	1000	990	995	992	992.3	-7.7
.2051	1200	1200	1200	1200	1200.0	0
.2373	1400	1390	1395	1395	1393.3	-6.7
.2689	1600	1590	1600	1595	1595.0	-5.0
.3013	1800	1800	1800	1800	1800.0	0

TABLE 4

HEAD-SPEED DETERMINATION FOR BENDING TEST OF PLASTICS

[Clutch pulley, fast; test duration, 5 min.; gear combination of 1 and 2]

Date of test January 1941	Motor rheostat setting	Distance traveled (in.)	Head speed (in./min)
8	835	0.187	0.0374
8		.188	.0376
8		.188	.0376
	Average		0.0375
8	1110	.2475	.0495
8		.2495	.0499
11		.2475	.0495
11		.2475	.0495
11		.2475	.0495
11		.2470	.0494
11		.2475	.0495
16		.2500	.0500
16		.2502	.0500
16		.2500	.0500
16		.2450	.0490
16		.2500	.0500
16		.2490	.0498
	Average		0.0496

TABLE 5

EFFECT OF WATER ABSORPTION ON ACCURACY OF SPECIFIC GRAVITY VALUES

[Water-displacement method; water temp., approx. 77° F]

Percent filler	Weight			Specific gravity		Error in specific gravity due to immersion
	In air (grams) (1)	In water (grams)	In air (grams) (2)	(1)	(2)	
80	1.8900	0.5268	1.8910	1.3864	1.3862	0.0002
80	1.9248	.5399	1.9255	1.3898	1.3987	.0002
60	3.0712	.8168	3.0712	1.3623	1.3623	0
60	3.1003	.8309	3.1005	1.3661	1.3661	0
40	3.0539	.7592	3.0541	1.3308	1.3308	0
40	3.0592	.7692	3.0593	1.3359	1.3359	0
20	3.2058	.7316	3.2058	1.2957	1.2957	0
20	3.1797	.7358	3.1797	1.3011	1.3011	0

[1]Before immersion.

[2]After immersion.

TABLE 8

PERCENT WATER ABSORPTION OF A PHENOL-FURFURAL PLASTIC

OF VARIOUS RESIN FILLER COMBINATIONS

AFTER 24-HOUR IMMERSION

Filler in molding powder (percent)	Molding temp. ^{o}F	
	325	375
10	0.36	0.50
20	.34	.55
30	.44	.55
40	.52	.65
50	.69	.84
60	.91	.99
70	1.26	1.32
80	2.40	3.04

NACA Technical Note No. 878

TABLE 9

VALUES OF MAXIMUM FIBER STRESS FOR PLASTIC TEST BARS

[Average of five tests is given unless otherwise specified; max. fiber stress is given in lb/sq in.]

Molding conditions: Temp. °F	Molding conditions: Press. (lb/sq in.)	Durite molding powder	Wood flour-resin mix	Carbon black-resin mix: Original	Carbon black-resin mix: Remixed (24 hr)	Carbon black-resin mix: Remixed (48 hr)	Acetone-wood flour-resin mix	Acetone-carbon black-resin mix
325	2000	11,550	11,622	1100	5530	[a]6643	11,080	5469
375	2000	11,994	11,850	----	5916	[b]6643	------	----
325	3000	11,600	------	----	[b]4370	5852	[a]10,600	5275
375	3000	12,120	11,356	----	5090	[c]5360	------	[d]4925

[a]Average for three tests.
[b]Only one successful test.
[c]Average for four tests.
[d]Average for two tests.

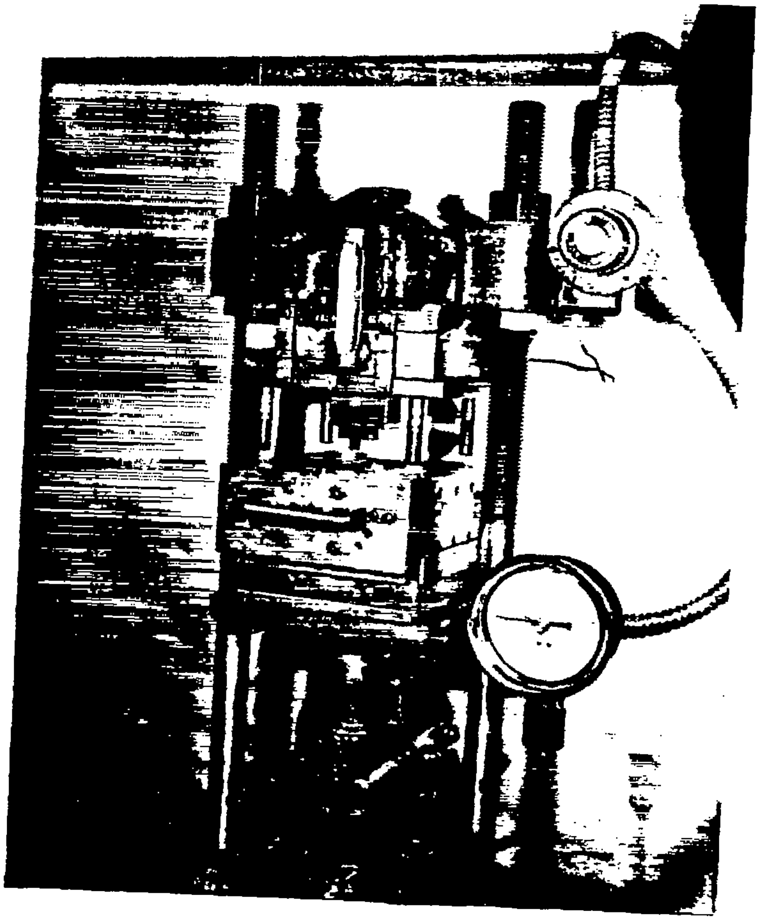


Figure 1.- Elmes 20-ton hot plate press

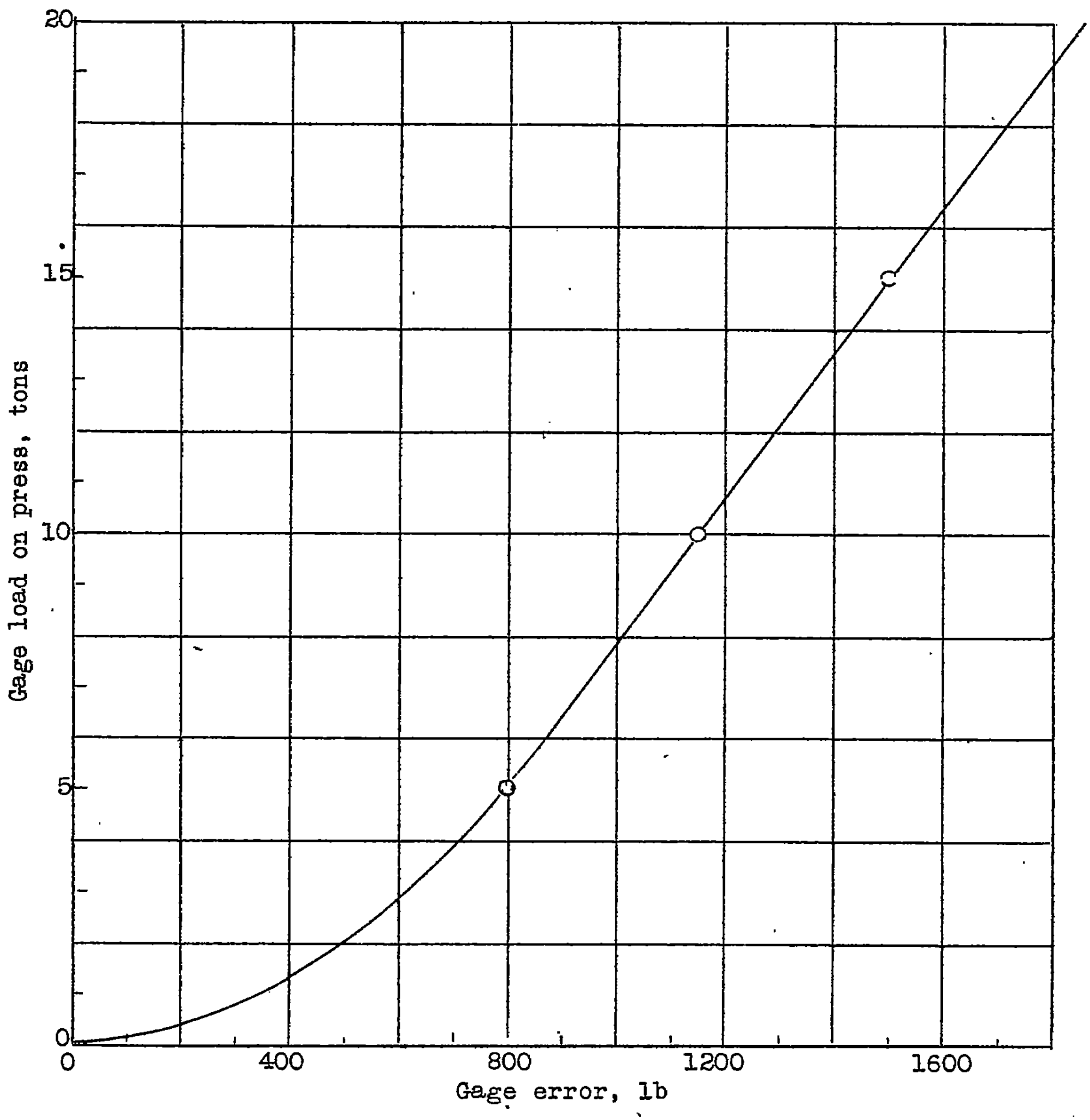


Figure 2.- Calibration curve for 20-ton Elmes molding-press gage. Correct gage setting is obtained by adding error to gage reading.

Figure 3.- Mold for producing flexural-strength test bars.

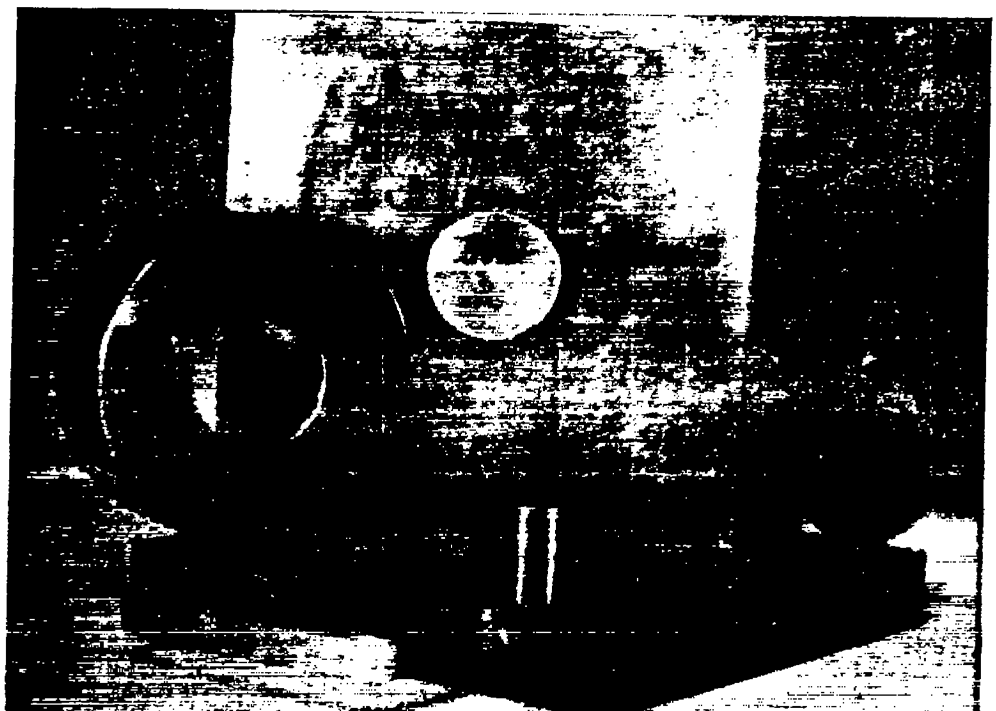


Figure 4.- Mold for producing water-absorption disks.

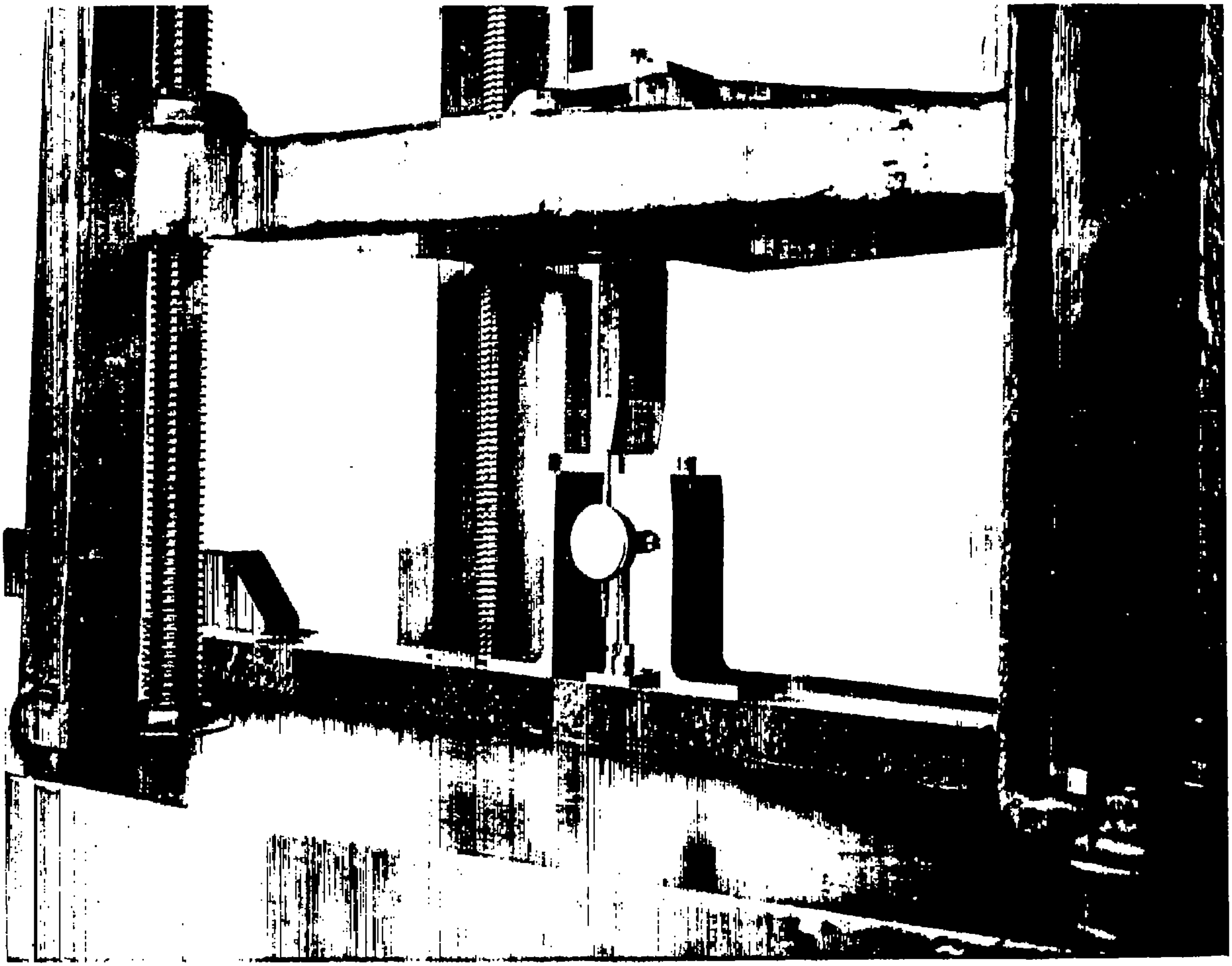


Figure 5.- Equipment Used for Making Flexural-Strength Tests

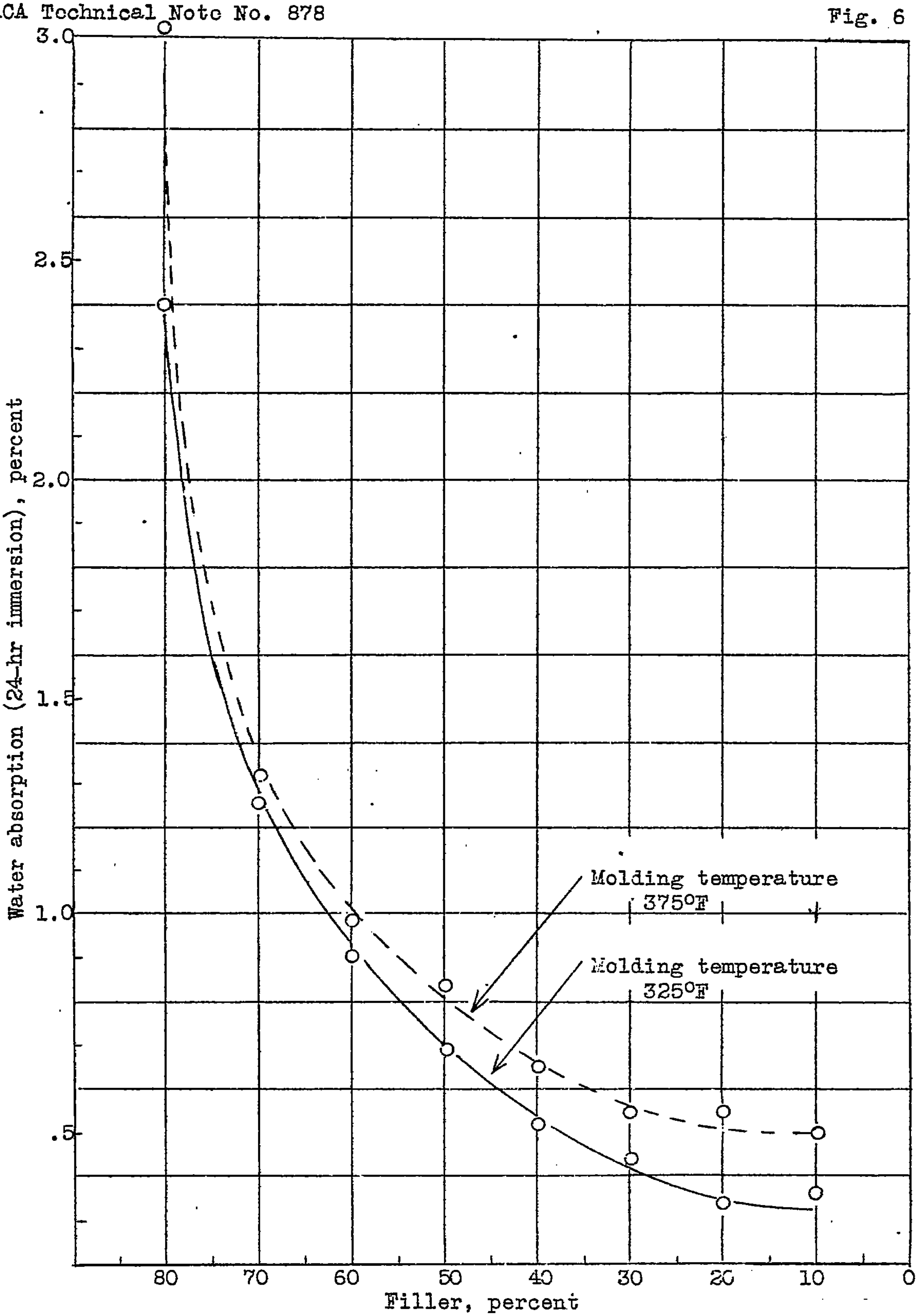


Figure 6.- Effect of molding temperature on the water absorption of a phenol-furfural plastic of various resin-filler combinations. Absorption based on weight after conditioning at 122°F for 24 hours.

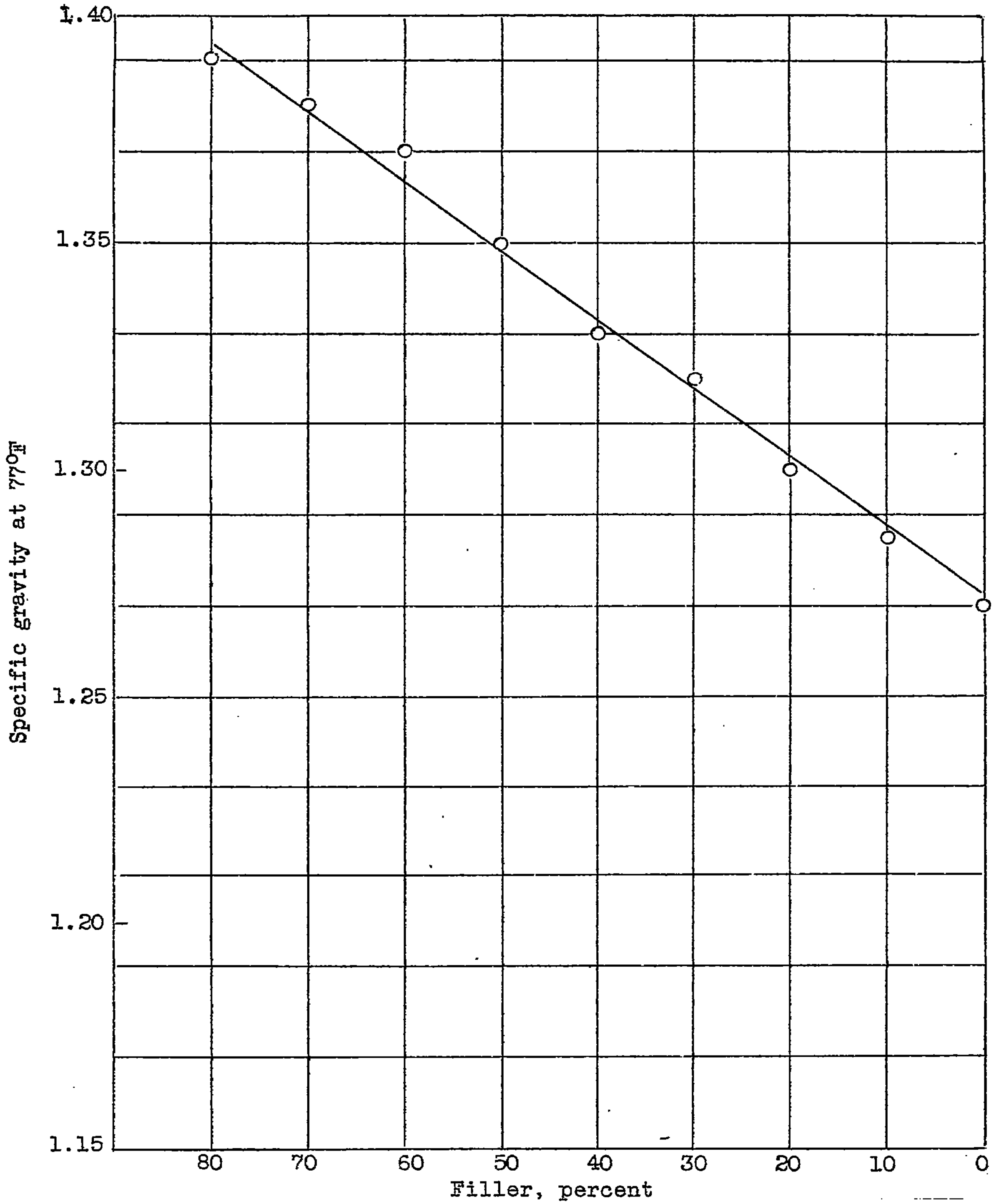
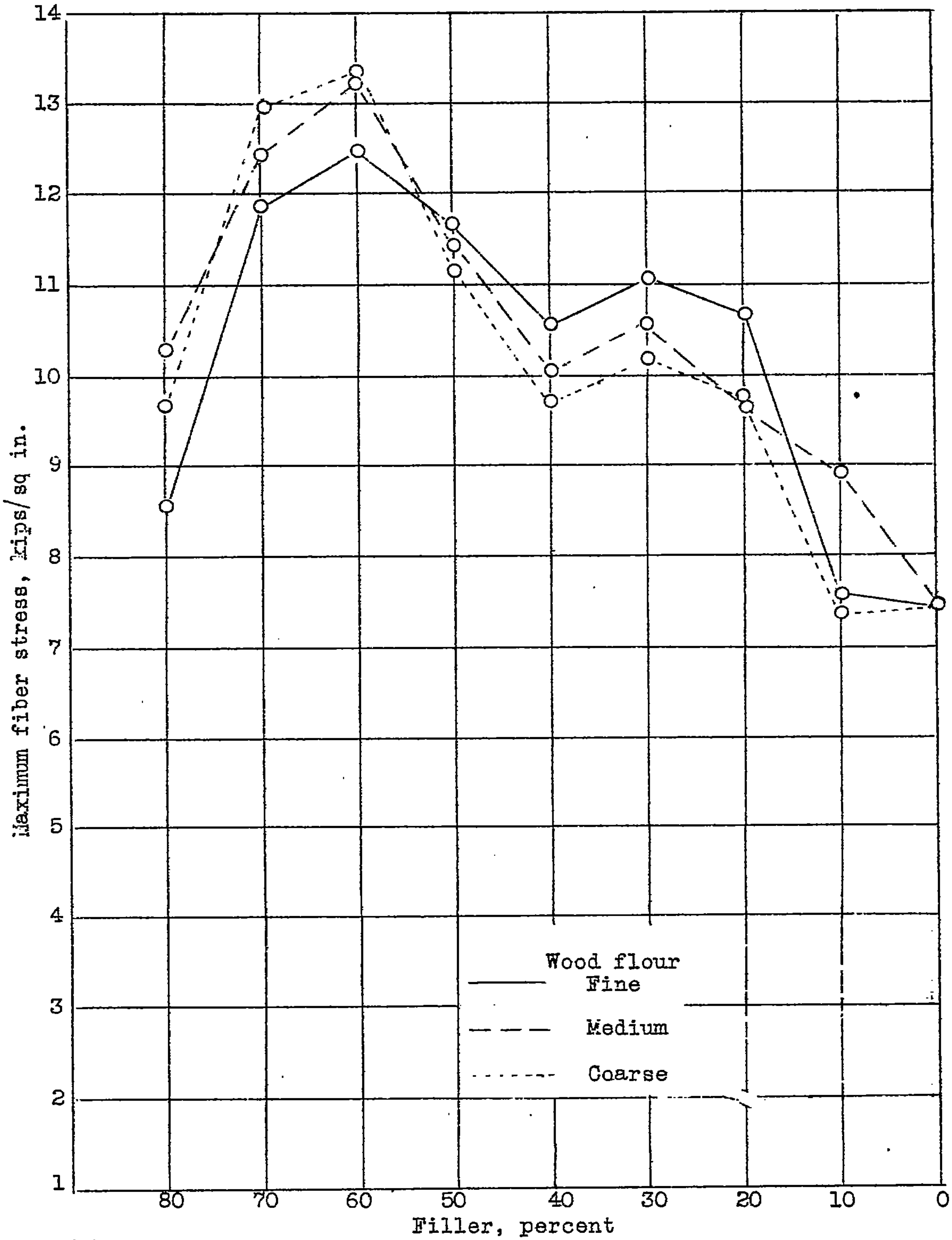
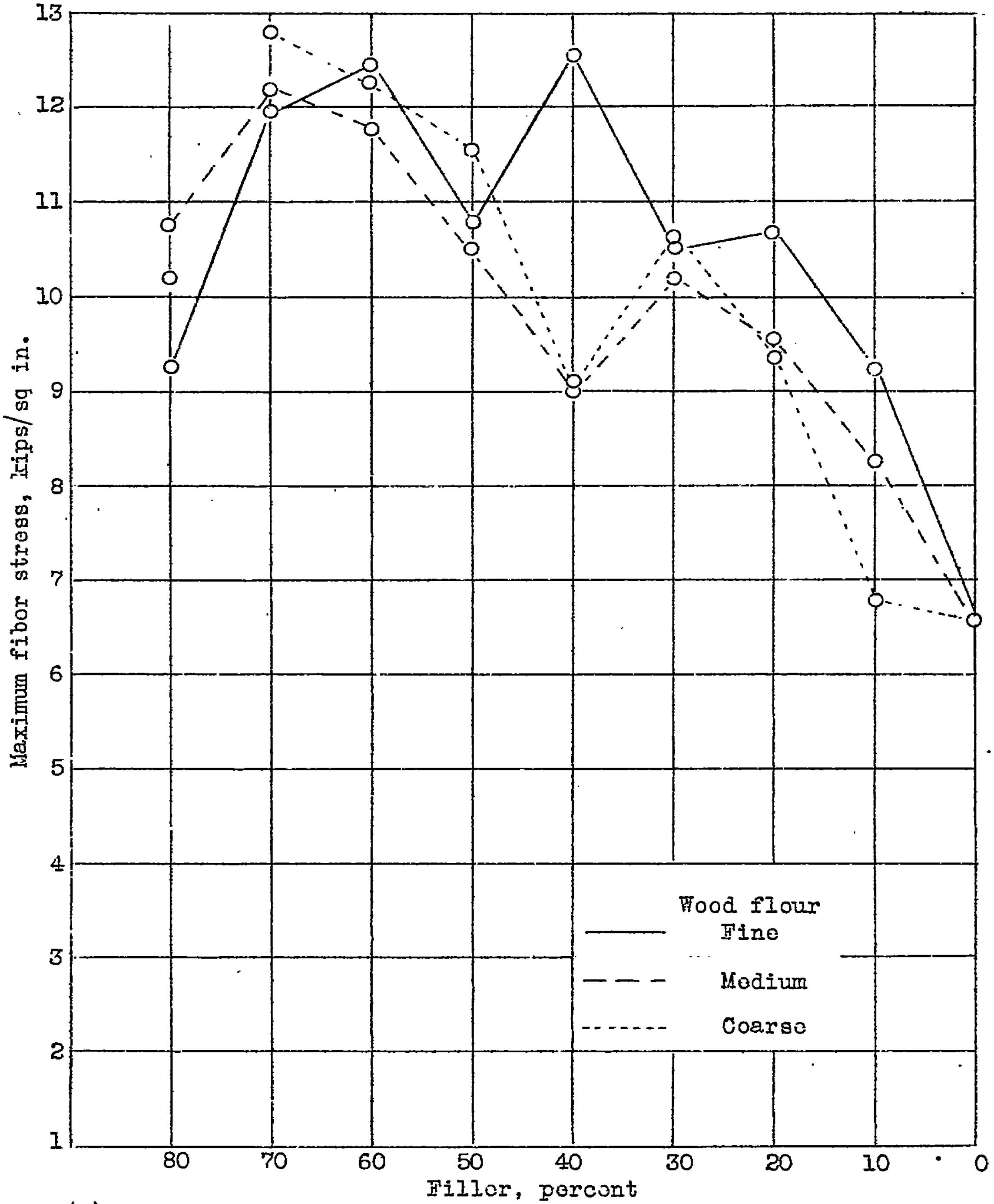


Figure 7.- Variation in specific gravity of a phenol-furfural plastic with different combinations of filler-resin content.



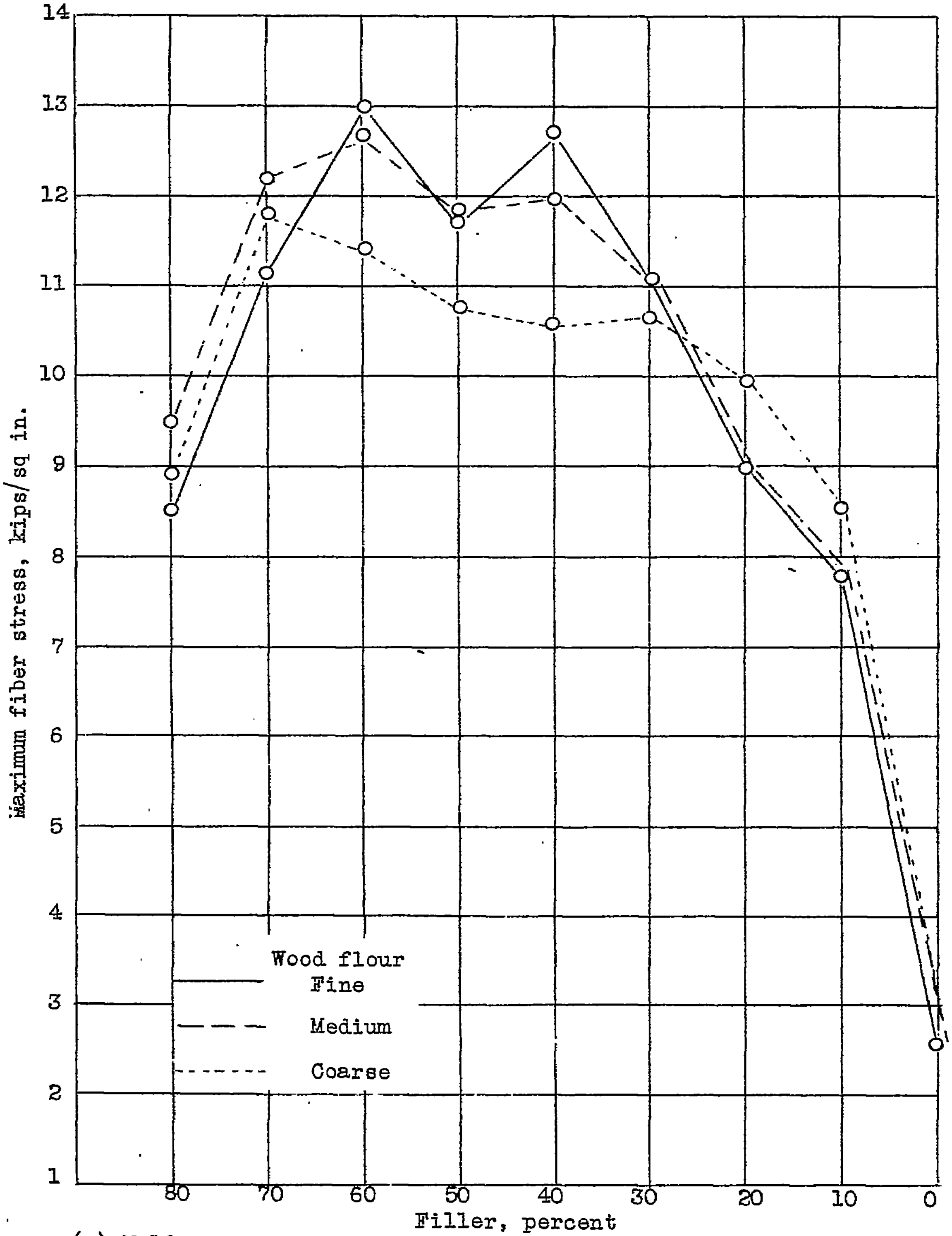
(a) Molding conditions, temperature, 325°F, pressure, 2000 pounds per square inch.

Figure 8(a to d).- Flexural strength of phenol-furfural plastics of various percentages of fine, medium, and coarse wood flour as filler.



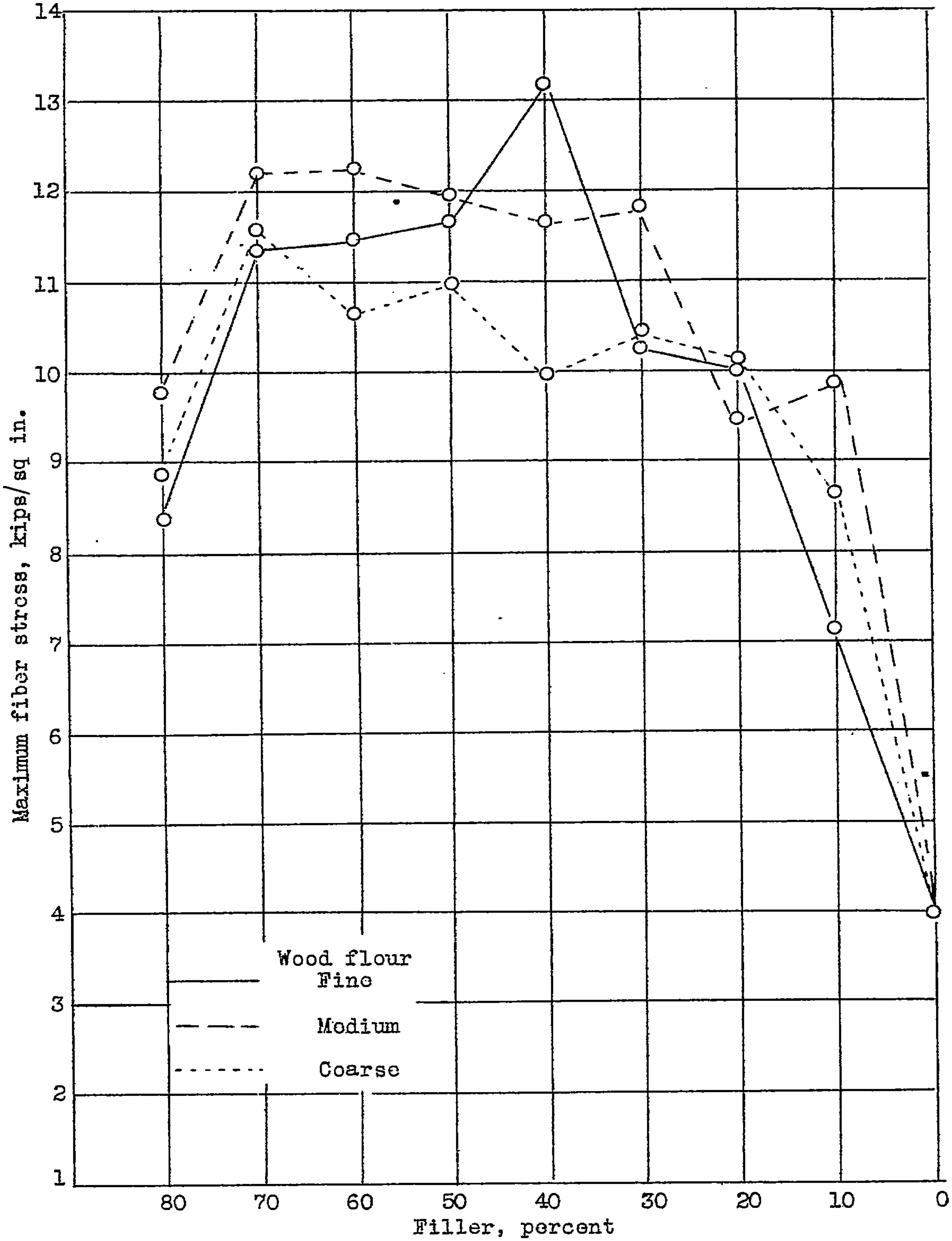
(b) Molding conditions: temperature, 325°F; pressure, 3000 pounds per square inch.

Figure 8.- Continued.



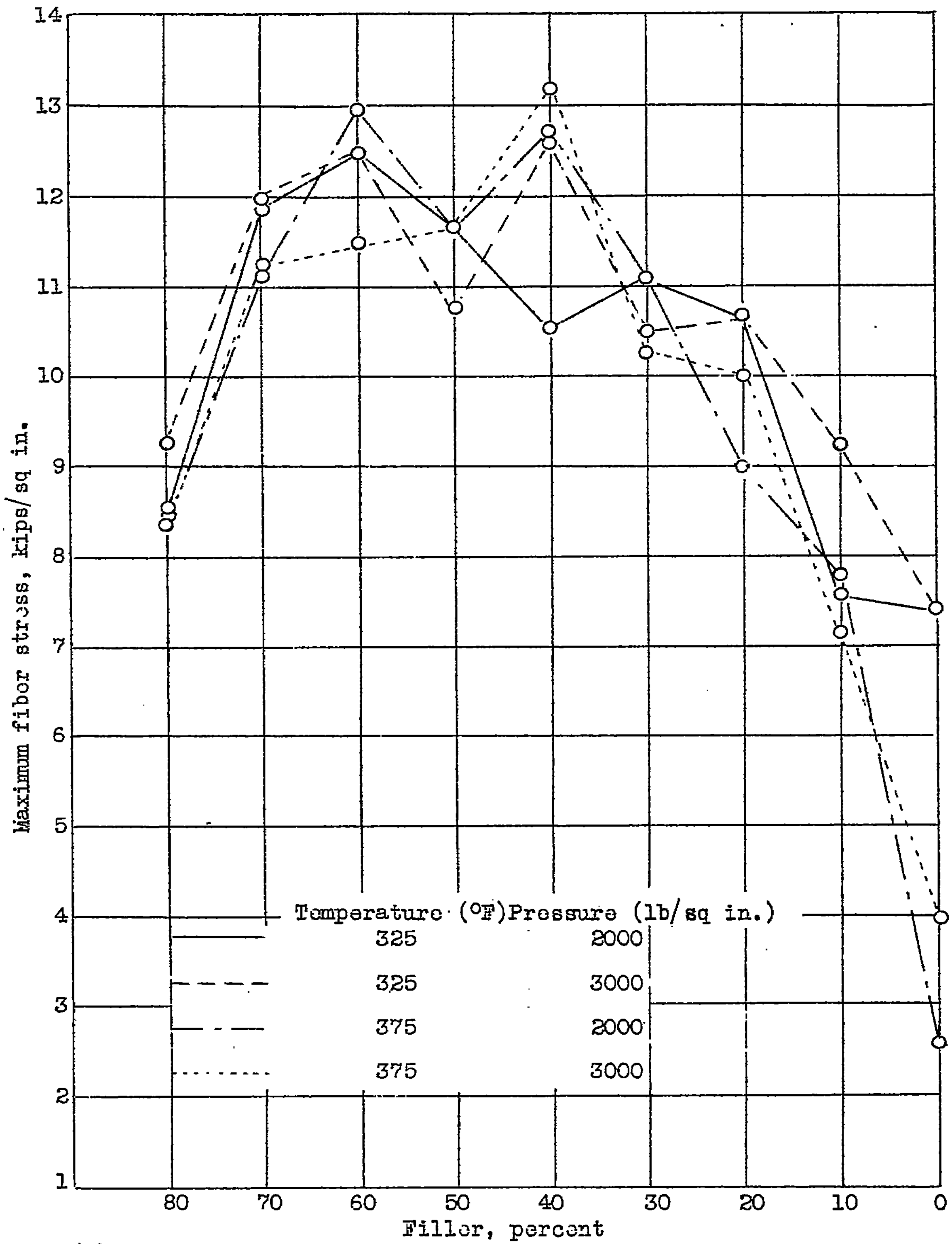
(c) Molding conditions: temperature, 375°F; pressure, 2000 pounds per square inch.

Figure 8.- Continued.



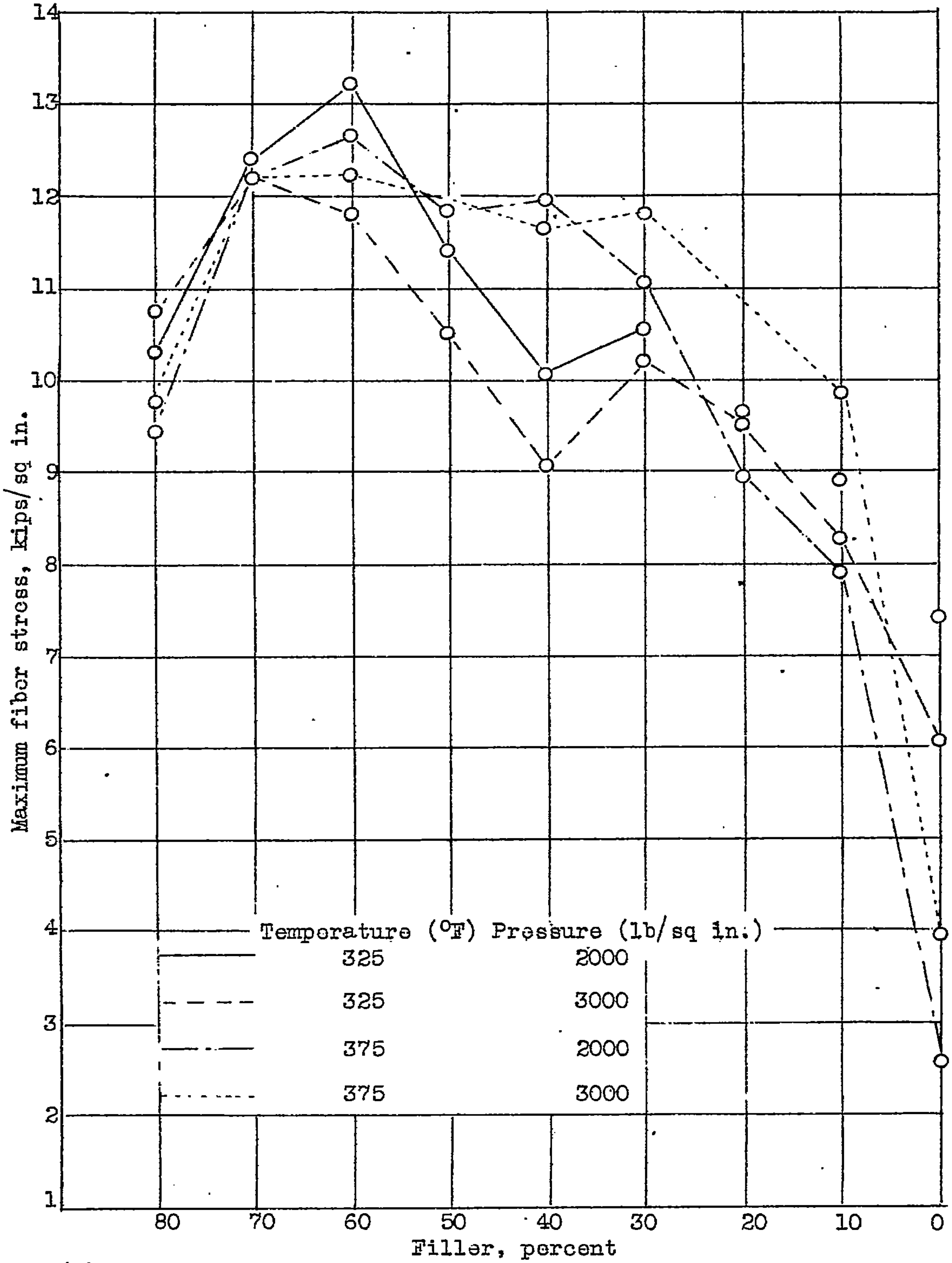
(d) Molding conditions: temperature, 375°F; pressure, 3000 pounds per square inch.

Figure 8.- Concluded.



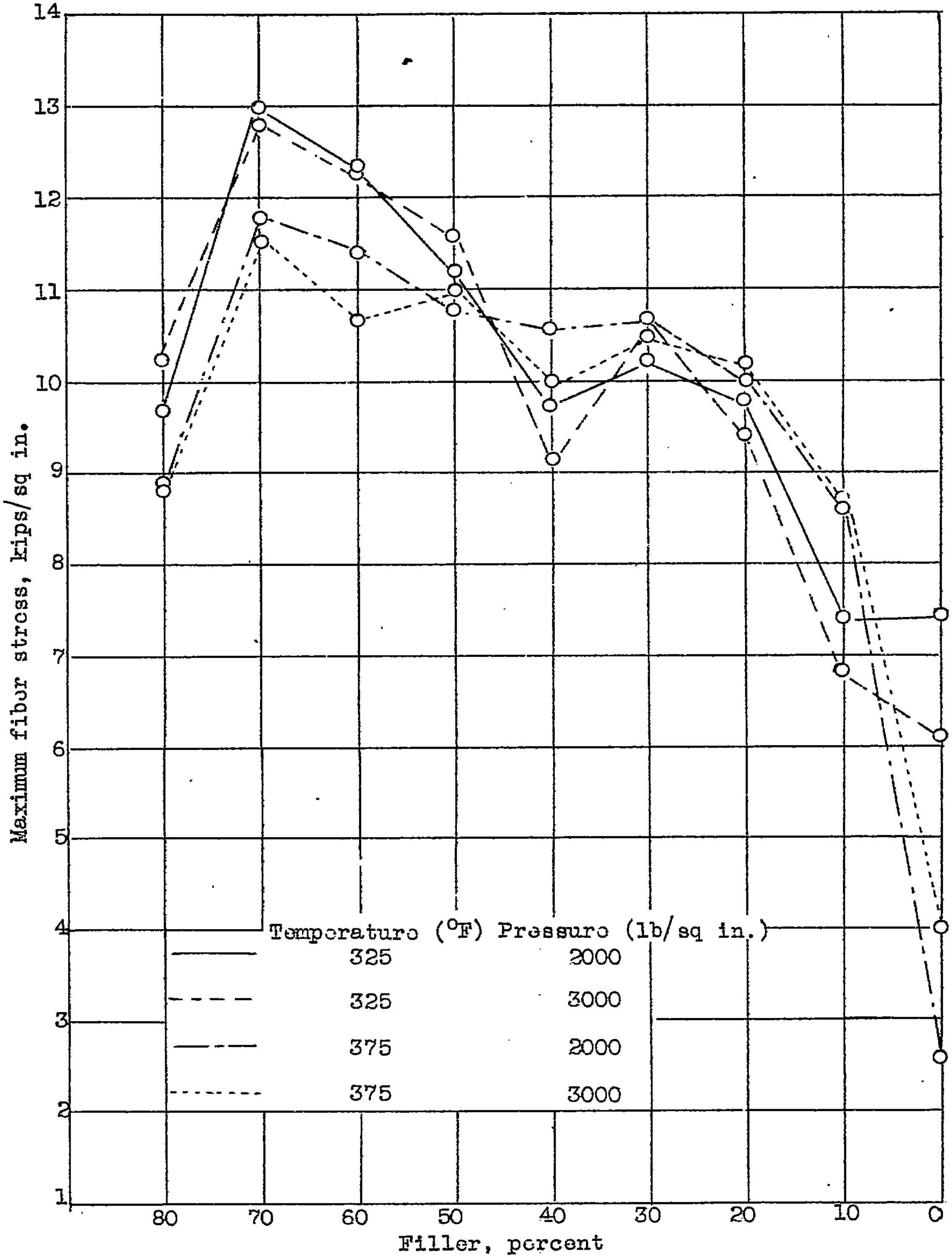
(a) Filler, fine wood flour

Figure 9(a to c).- Flexural strength of a phenol-furfural plastic molded under varying conditions of temperature and pressure.



(b) Filler, medium wood flour

Figure 9.- Continued.



(c) Filler, coarse wood flour

Figure 9.- Concluded.

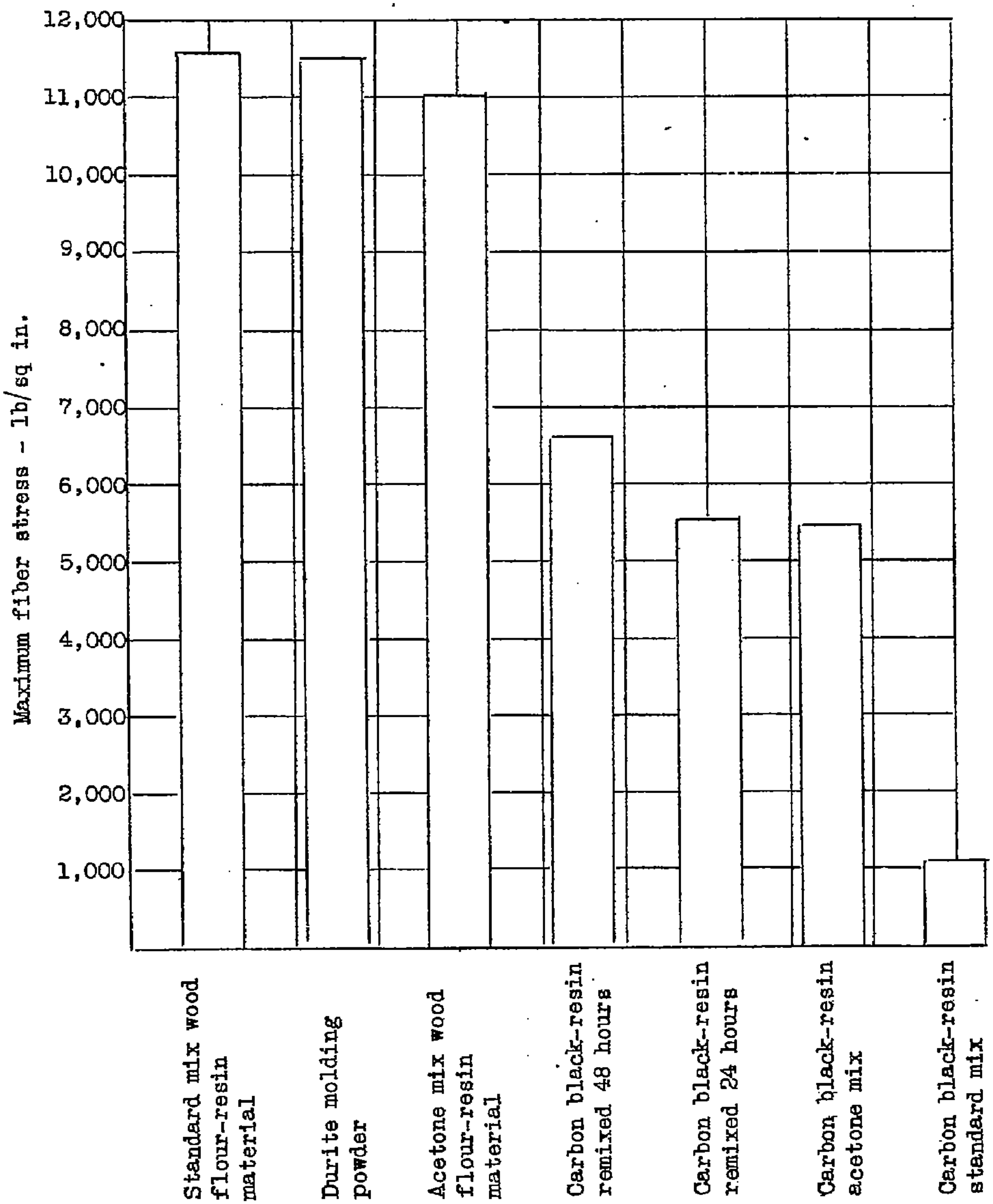


Figure 10.- Summary of results of tests for flexural strength of plastic-filler test bars. Molding conditions: temperature, 325°F; pressure, 2000 pounds per square inch; time, 15 minutes.